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Adhesive Bond of Steel & Concrete

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THE ADHESIVE BOND OF STEEL AND CONCRETE

...BY...

John Wolfersperger Davis

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1904

May 27, 1904.

This is to certify that the following thesis, prepared under the direction of Professor A. N. Talbot, Head of the Department of Municipal and Sanitary Engineering, by JOHN WOLFERSPERGER DAVIS, entitled THE ADHESIVE BOND OF STEEL AND CONCRETE, is accepted by me as fulfilling this part of the requirement for the degree of Bachelor of Science in Civil Engineering.

Ira O. Baker.

Head of the Department of Civil Engineering.

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The Adhesive Bond of Steel and Concrete.

Reinforced concrete is a material of great and growing importance in modern structural work. The ease and rapidity with which it may be used and the facility with which the ingredients of the composition may be obtained in almost any locality are greatly conducive to this. An equally significant reason for its importance is the wide range of uses to which it is applicable not only in engineering but in more common practice. Its utility extends from fence posts to bridges, including such things as sewers, monuments, trolley poles, grain elevators, foundations and even entire buildings, besides countless other more or less important uses. Its growth into common use has come so quickly that it has not been thoroughly investigated and all of its properties discovered and analyzed as in other constructional materials such as steel eye beams and channels. The properties of reinforced

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concrete beams are at present being quite thoroughly studied. One of these properties is the bond required between the steel and concrete in order that the induced stress may be transmitted from the steel bar to the concrete. The stress so transmitted is commonly known as shear, and is similar to that transmitted through the rivets in the flanges of plate girders. There have been a number of forms of bar introduced to increase the strength of this bond, such as the twisted bar, the corrugated bar, and the "Thacher" bar. Tests have been made to determine the relative stresses which could be put upon the various bars and also the amount which may be placed upon plain bars. These tests have been relatively few and not very accurate however. It seemed to the writer that the subject of the previous experiments had placed upon the wrong hypothesis in several instances, as noted by Talbot and later and hence arrived at erroneous conclusions. In order then to test his views the writer decided to determine by tests the bond formed between steel and concrete. The tests

used methods differing in some respects from those heretofore used and the results show that his methods are satisfactory.

Of the data available in this connection probably the most complete are the results of the experiments of Prof. C.W. Spofford of the Massachusetts Institute of Technology. His experiments were made in the laboratories of the Institute. The data is given in Table II. The statement of his method is as follows: "Portland cement concrete was used, made in the following proportions by weight: One part cement; three parts, sand; six parts, broken stone. The mixture, however, is very lean and would not again be used." The writer takes occasion here to disagree with the latter statement. He sees no reason why such proportions should give lean concrete, unless a poor grade of cement was used, or unless the concrete was poorly mixed and tamped. These proportions, or even richer, are commonly used in practice and give good satisfaction. "The sand was clean, but as the coarse gravel contained approximately 41 per cent. of sand. The broken stone was a mixture of two-parts of 1 in. trap

and one part of ½ in. trap. The mixing was thoroughly done by hand, the concrete being wet enough, when tamped into the molds to flush water to the surface. The loads were thoroughly cleaned by a sand blast, thus insuring uniformity in the surface condition.

A 100,000 lb. Olsen vertical testing machine was used to test the short uprights carrying the platform upon which the specimens were placed. The load upon the bearing ends of the concrete blocks was distributed by the interposition of a sheet of ½ in. felt between the concrete and the circular steel ring resting upon the platform of the machine. In all cases the rod projecting a short distance at the upper ends of the blocks (the rod being downward at the lower end) and the projecting end being carefully watched to detect the first evidence of slipping. The loads used were rounded, square, flat, twisted, Thacher and Johnson.

It will be observed from these tests that:

(1) Different types of bars of the same nominal size do not furnish the same net sections.

(2) The results of tests of the small size bars are consistent but the results of tests with the

1⅛ in. and 1¼ in. bars show that the concrete was broken by indirect stress due to imperfect bearing in the testing machine and hence the adhesion or bond of the latter bars was not determined.

(3) The bond of plain bars is not uniform. Other tests have shown that this bond is readily destroyed by shocks or repeated stresses."

The writer wishes to criticise the length of bar embedded in the concrete used in these experiments. There could be no possible object in having the bar embedded for such a length as 36 to 50 in. except for the purpose of anchorage. In actual practice the reduction in tension causing the shear is distributed over a considerable length so that the adhesive bond brought into action is quite evenly distributed. For example if a bar, ½ in. square in a beam 15 ft. long be stressed to the elastic limit in the middle, with say 10,000 lbs., there may be at the quarter point only 5000 lbs. and at the end the stress will be zero. This decrease of stress and the corresponding shear is distributed along the length of the bar. With a test bar, embedded in concrete, the full stress in the metal bar may not be

transmitted may fail into the concrete, previously to with the method of testing. The bar just as there the concrete is stretching while the concrete next it is compressing, and hence the adhesive stresses called into action must be much higher just within the concrete than at some distance in. Test pieces of considerable length therefore do not show the adhesive strength distributed and give misleading results. In this series experiments the writer used 12 in. and the results justify the statement that this is probably too long. The tests with the rod embedded 24 in. in the concrete go to show this. In every instance the pound per square inch of surface was much lower than in those embedded only half as deep. The writer would suggest for further experiments a depth of 9 or even 6 in.

In the tests for this thesis Portland cement concrete was used, made in the following proportions by loose measure: one part, cement; three parts, sand; and six parts, broken stone. This mixture is the same as was used in some experiments on reinforced concrete beams which were tested at the same time,

and gave very satisfactory results. The sand was clean, fairly free from clay and sharp. It was medium fine grained and contained approximately 30 per cent. of voids. The broken stone was a Hardwicke limestone, free from dust, having been passed over a 1/4 in. screen. It all passed a 2 in. screen, 15 per cent. was retained on a 1 in. mesh and 14 per cent. failed to pass a 1/4 in. mesh. It had approximately 44 per cent. of voids and weighed 85 lbs. per cubic foot loose. The cement was "Chicago AA" Portland. Standard test requirements were made neat and was allowed to stand one day in moist air and the remainder of the time in water, at 7 days showed an average ultimate strength of 755 lbs. per square inch and at 28 days no increase. Similar requirements made of mortar of one part cement and 3 parts sand showed at 7 days an average ultimate strength of 410 lbs. per square inch. The mixing of the concrete was thoroughly done by hand on a clean mixing platform and the concrete was well tamped into the moulds, the consistency being just enough so that it flushed to the

to the surface when tamped. The dry concrete used was so dry that it was crumbly and would hardly hold together when squeezed in the hand. To get it compacted required extremely hard tamping for a much longer time than for wetter. The molds were of sheet iron in the form of two half cylinders and overlapped one inch at either side when put together. Each was bound with a strap of sheet iron at the top and bottom, each strap being held by a bolt and nut. When put together the mold formed a cylinder 12 in. deep by 6 in. in diameter. The mold was supported in an upright position by being set in a hole in a 12 in. by 12 in. plank, cut 1/4 in. in diameter greater than the cylinder. The concrete was allowed to set for 24 hours.

In 1900 the Philadelphia testing machine was used. The load upon the bearing ends of the concrete block was distributed by putting a 1/2 in. cast iron plate upon it with a layer of slow setting plaster of paris between. The rods were 27 in. long, the remaining 15 in. being run up through the bearing blocks and into the grips. After the rod was fastened

in the grips the bearing [illegible] was run down upon the cylinder, so as to spread the plaster of paris and distribute the load uniformly. The rods used were round, square, twisted and [illegible]. The bars marked (*) in Table I were struck six months previously having been [illegible] with a 10 lb. sledge. See Table I for the data on these experiments.

Plate I shows that the bearing power decreases with the size of the rod and the depth embedded in the concrete. This confirms the results of Prof. Sprague.

Plate II shows the result of tests on the plain and on the corrugated rods.

Plate III contains the results of all the best pieces except those in which there were some peculiar conditions as those embedded 24 in. and so on.

The results of these tests show that:

(1) The bond per square inch of surface decreases with the size of the bar, after the bar gets above the medium size, that is above 3/4 in. This holds true for both plain and corrugated bars as shown by Prof. Sprague's experiments.

(2) 2 inches have no effect on the flexure. This is in direct contradiction to Prof. Spofford's statement that "The law of flexure is not uniform. Tests have shown that the bond is readily destroyed by shocks or repeated stresses." The writer gave particular attention to this in his tests and found that the average bond per square inch of surface was as high as that of those bars not disturbed.

(3) 12 ins. is probably too great a depth to embed the bars.

(4) The bond decreases with the depth of bar embedded. (3) and (4) apply to test pieces only and not to the case of the ordinary reinforced concrete beams. Both of these results have been discussed earlier in the article.

(5) Dry concrete is better than wet. Though this held true in these experiments it is doubtful whether it would in practice because of the excessive amount of tamping required.

(6) From the high values given by the twisted strands of farm fence wire embedded

in concrete it seems to the writer that a new device with great holding power, would be two $\frac{3}{8}$ in. bars twisted one about the other. The concrete well tamped about the threads thus formed should not yield easily.

From the tests made on bars set within $1\frac{1}{2}$ in. of the edge of the concrete the writer draws the conclusion that for bars not exceeding $\frac{3}{4}$ in. in diameter, there is necessary for test pieces

Plate I

Johnson Bars.

Spofford's results.

Bar	embedded.	
½-12"	16"	26"
¾-20"	24"	36"
1¼-27"	37"	50"

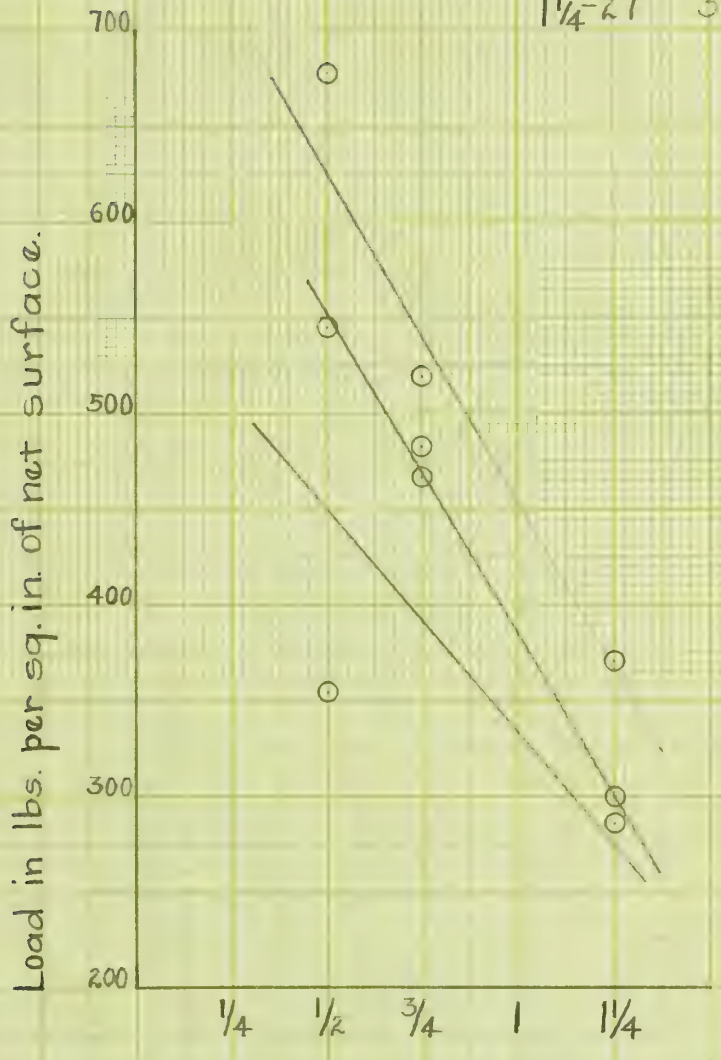
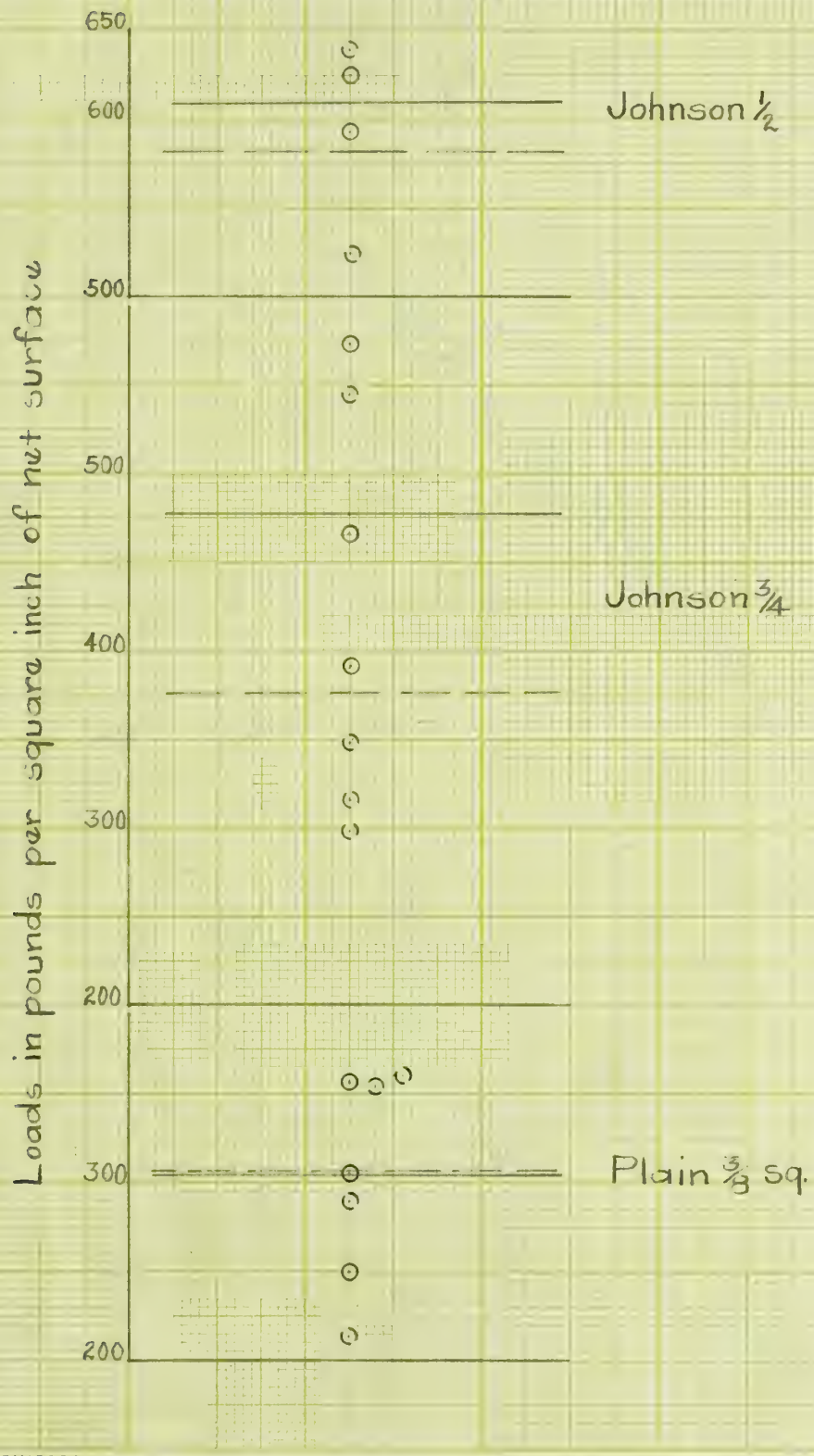


Plate II

Effect of Impact.

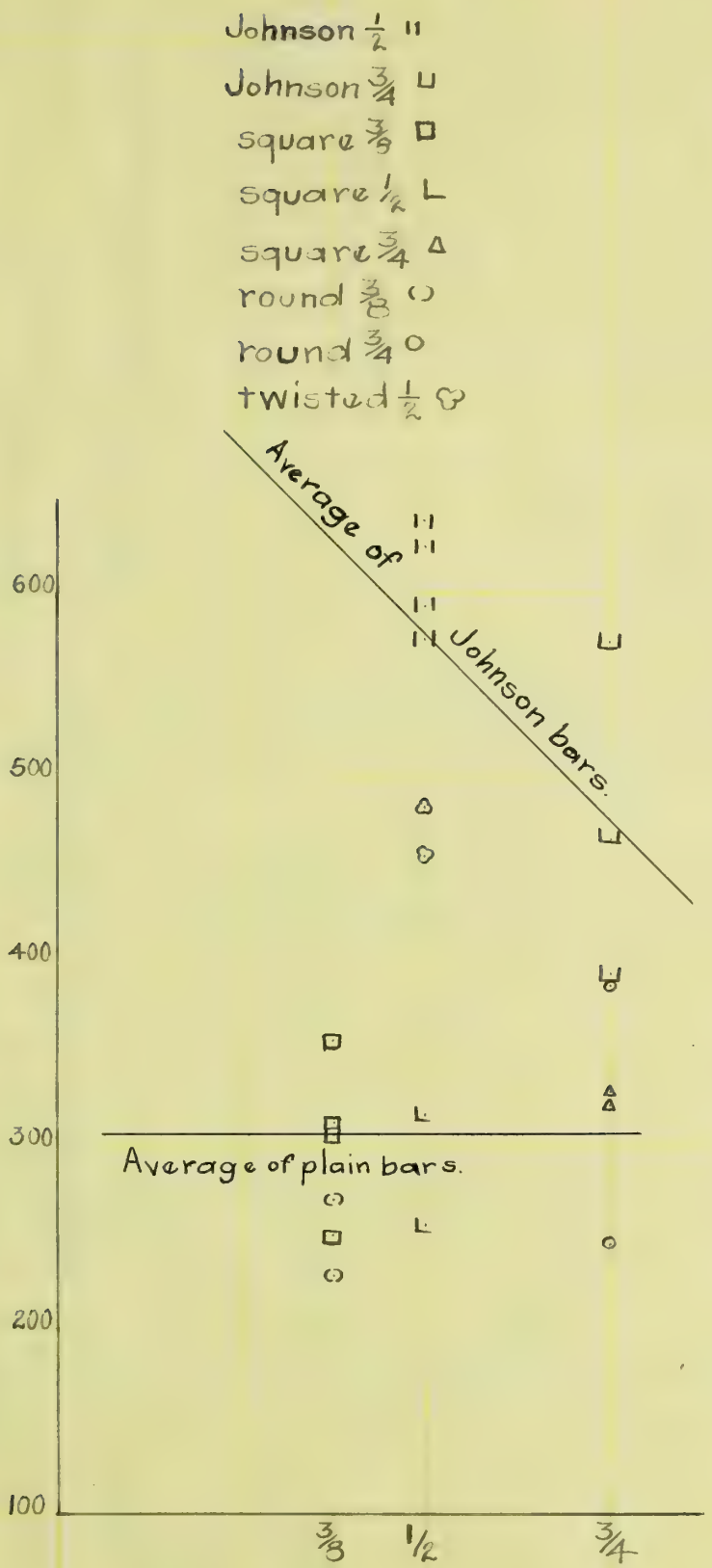
– – – – Bars disturbed

——— Bars not disturbed.



EUGENE DIETZGEN CO., CHICAGO.

Plate III.


Johnson 1/2
Johnson 3/4
square 3/8
square 1/2
square 3/4
round 3/8
round 3/4
twisted 1/2
Average of Johnson bars.
Average of plain bars.
600
500
400
300
200
100
3/8
1/2
3/4

No. of test	Type of rod.	Breaking load, lbs.	Area. sq.in.	Lbs. per sq.in. of net section	Lbs. per sq.in. of net surface.	Elastic Limit	Ultimate Strength	Remarks.
1	Johnson 1/2	14990	.194	77750	625	62000	90750	Concrete split
2	" "	14210	" "	73600	593	" "	" "	" "
3	" " *	12605	" "	65100	525	" "	" "	" "
27	" *	15335	" "	79250	639	" "	"	Cylinder broke
4	Johnson 3/4	17175	.333	51600	573	58300	98400	Concrete split.
30	"	11755	" "	35300	392	" "	" "	" "
26	"	13975	" "	42000	466	" "	" "	" "
5	" *	16360	" "	49100	545	" "	" "	" "
31	" *	9515	" "	28700	317	" "	" "	" "
32	" *	8960	" "	26900	298	" "	" "	" "
29	" *	10435	" "	31400	348	" "	" "	" "
33	square 3/8	4180	.16	29900	250	45000	56400	Rod slipped
34	"	6850	" "	42800	357	" "	" "	" "
13	"	5850	" "	36550	305	" "	" "	" "
35	" *	6810	" "	42600	354	" "	" "	" "
36	" *	6910	" "	43200	360	" "	" "	" "
18	" *	4100	" "	25600	214	" "	" "	" "
14	" *	5560	" "	34700	290	" "	" "	" "
8	square 3/4	11600	.562	20620	322	35000	49500	" "
9	"	11850	"	21100	329	"	"	" "
10	square 1/2	7910	.27	29320	317	33300	46700	" "
15	"	6400	"	23700	256	"	"	" "
11	round 3/8	3255	.113	28800	228	42500	54100	" "
12	"	3860	"	34200	270	"	"	" "
16	sq. 3/8 24"	6905	.16	43150	180	45000	56400	" "
17	" "	6690	"	41800	174	"	"	" "
19	Twisted 1/2	12060	.27	44650	483	33300	46700	" "

Table I

No. of test.	Type of rod	Breaking load, lbs.	Area, sq. in.	Lbs. per sq. in. of net section.	Lbs. per sq. in. of net surface	Elastic Limit	Ultimate Strength	Remarks.
20	Twisted $\frac{1}{2}$	11440	.27	42400	457	33300	46700	Rod Slipped
21	sq. $\frac{3}{8}$ Position	4785	.16	29930	249	45000	56400	" "
22	" "	6000	" "	37500	312	" "	" "	" "
23	" Wet	4580	" "	28640	239	" "	" "	" "
28	" Dry	6540	" "	40800	340	" "	" "	" "
7	round $\frac{3}{4}$	7000	452	15500	245	40500	54300	" "
6	"	11000	"	27500	386	"	"	" "
24	Twisted Wire	1035					-	Wire broke
25	" "	1110		-			-	" "

Table I

Table II

No. of test	Type of rod in.	Size of concrete block, in.	Length of rod in concrete, in.	Breaking load, lbs.	Min. area of cross-section, sq.in.	Bond per sq.in. of net surface.	Stress on rod in lbs. per sq.in of net section.	Remarks.
1	Ransome $\frac{1}{2}$	6×6	12	12100	0.25	504	48400	Concrete split.
2	"	8×8	"	8300	"	346	33200	"
3	Johnson $\frac{1}{2}$	6×6	"	12200	0.14	678	87200	"
4	Ransome $\frac{1}{2}$	6×6	16	8100	0.25	253	32400	"
5	"	8×8	"	14000	"	438	56000	"
6	Johnson $\frac{1}{2}$	6×6	"	13120	0.14	545	93700	"
7	Ransome $\frac{1}{2}$	6×6	26	16800	0.25	323	67200	Concrete crushed
8	"	8×8	"	15000	"	288	60000	Rod slipped
9	Johnson $\frac{1}{2}$	6×6	"	13750	0.14	354	98400	Rod broke.
10	Ransome $\frac{3}{4}$	8×8	20	25900	0.56	431	46300	Rod slipped
11	Johnson $\frac{3}{4}$	"	"	27600	0.31	619	89100	Concrete split
12	Ransome $\frac{3}{4}$	"	24	31900	0.56	443	57000	"
13	Johnson $\frac{3}{4}$	"	"	25000	0.31	467	80600	"
14	$\frac{3}{4}$ round	"	"	15300	0.44	271	38400	Rod slipped
15	$\frac{3}{4}$ square	"	"	19700	0.56	274	35200	"
16	$\frac{3}{4}$ round	"	31	18600	0.44	255	42200	"
17	$\frac{3}{4}$ square	"	"	22600	0.56	243	40400	"
18	Ransome $\frac{3}{4}$	"	36	36600	"	339	63500	Concrete split
19	Johnson $\frac{3}{4}$	"	"	28000	0.31	483	90500	"
20	$\frac{3}{4}$ round	"	"	18600	0.44	219	42200	Rod slipped
21	$\frac{3}{4}$ square	"	"	23900	0.56	221	42700	"
22	Ransome $1\frac{1}{8}$	10×10	27	33100	1.27	273	26100	Concrete split.
23	Johnson $1\frac{1}{4}$	"	"	40100	1.00	311	40100	"
24	Ransome $1\frac{1}{8}$	"	37	26150	1.27	157	20600	"
25	Johnson $1\frac{1}{4}$	"	"	44200	1.00	300	44200	"
26	Johnson $1\frac{1}{4}$	"	50	57250	"	286	57250	"

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